Comparison between manual harvesting and mechanical harvesting

Abstract

This paper presents a thorough analysis of the differences between human and automated harvesting techniques in agriculture, including their categorization, impacts, difficulties, costs, and potential future developments. Manual harvesting, which involves labor-intensive methods, enables meticulous handling and yields top-notch product. However, it is constrained by expensive labor and the availability of workers only during certain seasons. On the other hand, automated harvesting improves efficiency and scalability, decreasing the need for human labor and boosting production. Nevertheless, this endeavor requires a substantial infusion of financial resources and may lead to increased harm to crops and compaction of the soil. The paper analyzes the economic consequences of both approaches, emphasizing the greater initial investment required for mechanical equipment compared to the continuous labor expenses associated with hand harvesting. This study addresses the difficulties of labor shortages, equipment maintenance, and adaptation to various crops and terrains. In the future, the incorporation of cutting-edge technology, like as robots and artificial intelligence (AI), has the potential to tackle these difficulties by providing more effective and sustainable methods for harvesting.

Keywords: Harvesting, mechanical, manual, challenges, mechanization 2.0

1. Introduction

Mechanized agriculture is crucial for the comprehensive socio-economic progress in terms of ensuring food security, enhancing value addition, generating job opportunities, alleviating poverty, and increasing export revenues [1]. The movement of agricultural workers to non-farm industries and the growing sensitivity to climate change provide significant challenges in meeting the expanding food demands of a rapidly growing population, particularly in emerging nations [2]. The methods used for harvesting in agriculture have seen major changes throughout the years, moving from ancient manual approaches to more complex automated systems [3]. The driving force behind this transformation is the need to augment efficiency, productivity, and sustainability in response to escalating global food requirements. For thousands of years, manual harvesting has been the foundation of agriculture. It involves employing basic equipment and human labor to carefully handle crops, which is especially important for valuable or fragile food. Nevertheless, this task requires a significant amount of manual work, consumes a considerable amount of time, and is becoming more difficult due to a scarcity of available workers and the subsequent increase in wages. On the other hand, mechanical harvesting utilizes advanced technology to automate the process of gathering crops, resulting in a significant decrease in the amount of time and manual work needed [4]. This approach is especially beneficial for extensive operations, when rapidity and effectiveness are of utmost importance. Although mechanical harvesting offers advantages, it also presents notable obstacles such as substantial upfront expenses, the risk of crop harm, and limited flexibility in handling diverse crop varieties and terrains. Furthermore, the ecological consequences and power use of mechanical harvesters are crucial factors to take into account. This review study seeks to provide a thorough comparison between human and automated harvesting techniques, analyzing their various benefits, constraints, and consequences for the agricultural industry. Through the examination of existing research and case studies, our objective is to comprehend the compromises inherent in different harvesting methods and determine the optimal practices that may provide guidance to farmers in selecting the most suitable approach for their individual requirements and situations. By doing this comparison research, our aim is to make a valuable contribution to the current discussion on how to improve agricultural methods in order to achieve both production and sustainability. Figure 1 depict the practices of manual and mechanical harvesting as shown below.

Figure 1. Practices of manual and mechanical harvesting [5]

Figure 2 illustrates two different methods of threshing crops, highlighting the contrast between manual and mechanical processes. In panel A, "Manual threshing," a farmer is depicted using a traditional method, where the crop is manually beaten against a hard surface to separate the grains from the stalks. This method is labor-intensive and relies heavily on human effort and physical strength, which can be time-consuming and less efficient compared to mechanical methods. The setting appears to be a rural field, with crops laid out on a tarp to facilitate the collection of separated grains. In panel B, "Mechanical threshing," several individuals are shown operating a mechanical thresher. This device automates the threshing process, significantly speeding up the separation of grains from the stalks. The presence of multiple people suggests the necessity of coordinating the operation of the machine and handling the input and output of crops. The mechanical thresher represents a more efficient and less labor-intensive approach, capable of processing larger quantities of crops in a shorter period, thereby improving productivity. Manual method was Rs. 431.50 and Rs. 447.48 per hectare respectively [35].

Figure 2. Manual and mechanical threshing practice [5]

1.1 Classification of Harvesting system

The conilon coffee harvesting involves a number of sequential processes, including manual stripping and washing of the fruits [6]. The harvesting systems are defined by the methods used to execute the activities and their sequence [7]. Harvesting methods are categorized into two type's manual and mechanical which is described below.

Manual: A manual method is used for all the actions involved in harvesting, except for transportation. This technique requires a significant number of people per area. Currently, it is recognized as the dominating system in many places where crops are grown. The harvesting procedure might include either complete or targeted manual stripping. Total hand strip harvesting involves the complete removal of all fruits from the plants simultaneously, a practice that is prevalent in Brazil. The process of selective fruit harvesting is carried out systematically, specifically targeting just the fully ripe fruits such as cherries, raisins, and dried fruits. The number of passes will be determined by the uniformity of the blooming, development, and fruit maturity processes. Selective harvesting is not often used to augment labor demand and, as a result, minimize expenses. This is especially prevalent at establishments that specialize in high-quality, specialty coffees and small-scale production.

Mechanization: The strip harvesting process involves mechanized activities for harvesting, cleaning, and shipping. These operations are suitable for properties with considerable size, modern technology, and ideal terrain (with slopes less than 30%). Despite its name, the mechanical system does not entirely replace human labor, since the machines are unable to collect all the fruits off the plant. In most cases, further hand harvesting is still required. Therefore, any fruits that are left after the mechanical strip harvesting process are either manually or mechanically removed in an operation known as transfer, which is determined by the amount and technical and economic feasibility. This categorization of harvesting methods is didactic in nature, since in fact, it is not strictly followed. Manual harvesting involves certain mechanical operations, such as transportation, whereas mechanical harvesting does not include manual steps, such as manual transfer. Technically, the harvesting methods may range from manual to mechanical, depending on the amount of labor or machinery used in the execution of activities. The observed trend in conilon coffee culture is an increase of mechanized activities while maintaining a balance between human and mechanical labor.

1.2 Effect of Mechanical harvesting in Agriculture

The adoption of mechanical harvesting in agriculture has significantly impacted the industry, bringing about numerous changes and benefits, as well as some challenges [8][9]. Here is an in-depth look at these effects:

1. Increased Efficiency and Productivity

Mechanical harvesters significantly increase the speed and efficiency of the harvesting process. They can cover large areas in a fraction of the time it would take for manual labor, leading to higher productivity and allowing farmers to manage larger farms. This efficiency helps meet the demands of a growing population by ensuring a steady supply of agricultural products.

2. Labor Cost Reduction

One of the most notable impacts of mechanical harvesting is the reduction in labor costs. With machines taking over the bulk of the harvesting work, the need for large numbers of seasonal laborers diminishes. This reduction in labor dependency can lead to substantial cost savings for farmers, especially in regions where labor is expensive or in short supply.

3. Improved Crop Quality and Consistency

Mechanical harvesters are designed to harvest crops at optimal times and in a consistent manner, which can improve the overall quality of the produce. For example, mechanical grape harvesters can pick grapes at their peak ripeness, enhancing the quality of wine. Similarly, machines can reduce the likelihood of damage to delicate crops, ensuring more uniform and marketable produce.

4. Economic and Environmental Impacts

While mechanical harvesting offers economic benefits, it also has environmental implications. The use of heavy machinery can lead to soil compaction, which can affect soil health and crop yields over time. Additionally, the production and operation of mechanical harvesters contribute to greenhouse gas emissions. However, advancements in technology are leading to more fuel-efficient and environmentally friendly machines.

5. Job Displacement and Rural Economies

The shift to mechanical harvesting can lead to job displacement for farmworkers, particularly in regions heavily reliant on manual labor. This can have significant social and economic impacts on rural communities, where agriculture is often a primary source of employment. Addressing these challenges requires investment in retraining programs and the development of alternative employment opportunities.

6. Adoption and Technological Advancements

The adoption of mechanical harvesting varies across different crops and regions, depending on factors such as crop type, farm size, and economic conditions. Continuous advancements in technology are making mechanical harvesters more versatile, affordable, and efficient. Innovations such as precision agriculture, GPS-guided machinery, and automation are further enhancing the capabilities of mechanical harvesters.

7. Impact on Harvesting Timeliness

Mechanical harvesters allow farmers to harvest crops more quickly and within optimal windows of time. This timeliness can be crucial for crops that are sensitive to weather conditions or those that require rapid processing after harvest to maintain quality, such as fruits and vegetables. In conclusion, mechanical harvesting has brought significant changes to agriculture, boosting efficiency, reducing labor costs, and improving crop quality. However, it also poses challenges such as environmental impacts, job displacement, and the need for continued technological innovation. Balancing these benefits and challenges is essential for sustainable agricultural development.

1.3 Economics of manual and mechanical harvesting

Hassena et al. [10] conducted experiments at the Chilalo Agricultural Development Unit (CADU) in Etheya and Asasa as part of their research. It was discovered that the cost of hand harvesting and threshing per quintal was 21% and 25% higher in Asasa and Etheya, respectively, compared to the cost of combiner harvesting. Combiner harvesting resulted in a net benefit that was about 38% higher in Asasa and 16% higher in Etheya, compared to the traditional method of human harvesting and threshing. In their study, Abdul et al. [11] conducted tests on a combiner harvester (Class Denominator- 68) in Faisalabad. They found that the manual and reaper harvesting techniques had similar prices, amounting to `2400 per acre. In contrast, the combiner harvester had a much lower cost of `860 per acre. Using a combiner harvester instead of traditional techniques of wheat harvesting may result in a profit of around 1600 acres per unit. The combine harvester does not produce bhoosa, which is a byproduct of the other two harvesting processes. However, even after accounting for the cost of bhoosa, the use of the combine harvester resulted in a minimum gain of `731 per acre compared to the other harvesting methods. Padmanathan et al. [12] performed an experiment at Tamil Nadu Agricultural University, Coimbatore, where they noticed that using a groundnut combiner harvester resulted in significant cost and time savings compared to the typical technique of manual digging and stripping. The cost savings were 39% and the time savings were 96%. Mohammad and his colleagues [13] did a research at the Rice Research Institute of Iran. According to their study, the reaper's effective field capacity was 0.170 ha h-1, whereas manual harvesting had a capacity of 0.008 ha h-1. The labor requirements for reaper and hand harvesting were 5.88 and 128 man-hours per hectare, respectively. The grain losses experienced during manual harvesting and mechanical harvesting with a reaper were 7.33% and 6.83% respectively. There were no significant differences in the average losses between these two procedures. The cost of the harvesting operation, without including fees for threshing and handling, amounted to $88.88 per hectare for manual harvesting and $15.20 per hectare for reaper harvesting (automatic harvesting). Moussa, who is 26 years old, discovered that using a combiner harvester led to a reduction of 32% and 36% in harvesting expenses when compared to the semi-mechanical system (consisting of a mower, transporter, and thresher) and the traditional method (including human labor, transportation, and thresher), respectively. Pawar et al. [14] evaluated the efficiency of a SWARAJ 8100 combine harvester and an SAECO self-propelled vertical conveyor reaper combined with a thresher on a wheat crop. The assessment was conducted at MPKS Rahuri, and several cylinder speeds were tested. After comparing both machines, it was found that the cost of the combiner harvester was 817.84 ` ha-1, which was lower than the cost of the combination of the self-propelled vertical conveyor reaper with thresher (1816.79 ha-1). Hence, the utilization of a combiner harvester is more suited for expansive fields, whilst the amalgamation of a self-propelled vertical conveyor reaper with a thresher is more fitting for smaller fields. Bio-char is carbon-rich product generated from biomass through batch type slow pyrolysis [39].

The remaining structure of this paper are followed as: section 2 discussed the related work of our section 3 expenditure of manual and mechanical harvesting, section 4 discussed the challenges and solution of manual and mechanical harvesting, section 5 presented the mechanization 2.0 in harvesting and section 6 provided the conclusion of our study.

2. Review of literature

Kushwah et al., (2024)[15] examined that the process of harvesting cauliflower included manual work, which was both costly and time-consuming. This method sometimes resulted in substantial crop losses due to the indiscriminate removal of immature curds. There is a growing desire among individuals to develop specialized machines for harvesting cauliflower that can accurately identify and collect ripe, healthy heads while minimizing harm, wastage, and the need for labor-intensive tasks in order to address these challenges. The objective of this research piece is to provide a comprehensive review of the ownership and operating expenses associated with this specific kind of selective harvesting technology. Through the provision of accurate cost analysis, farmers may make informed decisions on the purchase of new machinery, the upkeep and protection of current equipment, or the investigation of alternative approaches to improve farm productivity and financial results. The economic assessment was conducted by computing operating costs using the straight-line method, in addition to examining the breakeven threshold and establishing the time it takes to recoup the investment. The ownership and operating costs of the advanced selective harvester are 58.41 and 75.5 rupees per hour, respectively. The comparison analysis demonstrates that the selective harvester has several advantages over traditional manual harvesting techniques. The selective harvester exhibits a remarkable 24.6% drop in expenses and a staggering 60.6% reduction in the amount of time needed. The findings emphasize the effectiveness and economic benefits associated with the use of selective cauliflower harvesting systems. Farmers use this analysis extensively to make informed decisions.

Khan et al., (2024)[16] Agricultural automation is crucial in the shift from subsistence farming to commercial agriculture, especially in labor-intensive tasks such as harvesting. This research evaluates the functional attributes of the BRRI Whole Feed Combine Harvester (Model BRRI WCH2021) in real-world field conditions. The technical performance and loss evaluation of the harvester were carried out in farmer fields in Bangladesh's Rangpur area during the Boro 2022 and Aman 2022 seasons, as part of the SFMRA project. The harvester's field efficiency was calculated to be 62.5% and 57.9% during the Boro and Aman seasons, respectively. The fuel consumption rates during the Boro and Aman seasons were reported at 2.77 l/ha and 2.31 l/ha, respectively. The combined losses from harvesting, including cutter bar, shatter, cylinder, and separation loss, had an average of 0.56% and 0.48% during the Boro and Aman seasons, respectively. The use of the BRRI Whole Feed Combine Harvester for mechanized harvesting resulted in a notable reduction of paddy losses by 5.81% in comparison to human techniques. The field assessment findings demonstrate that the combine harvester performed well, showcasing its ability to reduce the need for manual labor during the busiest times of harvesting. The BRRI WCH's development provides a sustainable option for mechanizing rice harvesting for forward-thinking farmers. It facilitates the wider implementation of sophisticated agricultural technologies in Bangladesh.

Cao et al., (2024) [17] intended that cotton is an essential primary resource for the textile sector, and the characteristics of its initial output significantly impact the attributes of the yarn and fabric. Nevertheless, the influence of low temperature and moisture return during ginning on the mechanical characteristics has not been well investigated. This research seeks to fill this need by developing and examining a plan for assessing the mechanical characteristics of machine-harvested cotton fibers that have undergone various moisture recovery levels and temperatures. Regression models were developed to analyze the correlation between temperature and mechanical parameters under varying moisture recovery settings. These models demonstrated strong consistency. In addition, the research investigates the mechanical damage mechanism of cotton fibers that occurs during the harvesting and ginning process by monitoring the fracture interface of various fiber samples. Specifically, fibers with little moisture recapture show a V-shaped fracture, while fibers with high moisture regain exhibit prominent fibrils that are visible on the fiber surface, leading to a ripping appearance at the fracture boundary. Overall, this research offers theoretical backing for improving the harvesting process in cotton processing companies by focusing on moisture recovery and low temperature. It also contributes significantly to the development of sustainable cotton fiber harvesting and processing technology.

Esau et al., (2023)[18] Several variables influence the effectiveness of mechanical harvesters, leading to different levels of productivity and losses across fields. Harvesting efficiency is influenced by several parameters related to the crop and topography, such as plant height, density, fruit diameter, slope, and elevation. The performance of mechanical harvesters is influenced by meteorological variables such as temperature, relative humidity, plant canopy wetness, and soil moisture. The positioning of sensors used for real-time yield monitoring, ground speed, head rotations, and head diameter are the mechanical variables that contribute to variations in harvested yield. The mechanical harvesting of wild blueberries is characterized by significant variability in harvesting efficiency. This variability is primarily attributed to many factors, including the scarcity of competent operators, the uneven topography of the fields, spatial changes in plant characteristics like as height, fruit zone, and density, as well as the relatively short duration of the harvesting season. This study introduced innovative strategies to address the mechanical harvesting difficulties encountered by the wild blueberry business. It focuses on enhancing the efficiency of the harvesting operation and processes by using precision harvesting technology. The goal is to enhance the picking efficiency and minimize losses. A highly effective harvester, equipped with cutting-edge technology and controlled with precise mechanical parameters that take into account geographical variances, has the potential to significantly enhance the profit margins of wild blueberry producers by minimizing harvesting losses.

Vimal et al., (2023)[19] studied that climate change has led to an increase in rainfall from tropical cyclones, which is having a significant impact on the agricultural sector, particularly paddy fields. Strong gusts of wind combined with heavy rainfall result in the lodging of paddy fields, making their harvest challenging. The presence of waterlogging in the fields renders mechanized harvesting techniques inefficient in this particular scenario. Utilizing a conventional sickle for manual harvesting is the only method to gather crops that have fallen over, in order to mitigate food security emergencies and minimize economic losses. Gathering the fallen paddy stems from the ground for manual harvesting is a time-consuming task that requires harvesters to hold an uncomfortable position for an extended length of time, in contrast to harvesting crops that are not lodged. The research included a sample of seventy-five female harvesters, ranging in age from 35 to 75 years. These harvesters were picked from both lodged and un-lodged small-scale agricultural areas in Kerala, a coastal state in southern India. An ergonomic evaluation was undertaken to compare and quantify bodily discomfort, perceived effort, postural hazards, and rate of production in both harvesting situations. The harvesters saw a substantial increase in physical discomfort, perceived effort, elevated posture hazards, and reduced production under lodged circumstances as compared to un-lodged settings. The process of harvesting crops that have fallen or become tangled poses significant hazards, has limited efficiency, and requires urgent implementation of ergonomic design measures to ensure the well-being of the harvesters. The developed implement was operated by the mini-tractor using three-point hitch, it performs both the operations of installation and retrieval of drip line [37]. That functions at forward speeds ranging from 0.7-9.7 kmph (0.43-6.0 miles/hour) and depths between 1 and 2 cm (0.39 and.78 inch)[38].

Morales-Sillero et al., (2023)[20] intended that Mechanical harvesting using over-the-row harvesters in super-high-density (SHD) table olive orchards enhances the efficiency of fruit extraction, but with the potential drawback of bruising that may compromise fruit quality. Furthermore, the occurrence of an early harvest during seasons that are less conducive to producing high-quality crops is becoming more often due to the effects of global warming. This research investigates the effect of early morning harvesting, when the ambient temperature is cooler, on the quality of olives. The research was conducted over a period of 2 years on two cultivars, 'Manzanilla de Sevilla' and 'Manzanilla Cacereña', which have varying levels of resistance to bruising. The plants were cultivated under SHD (super high density) conditions and were picked at two specific times: dawn and morning. The morphology of the fruit was not altered by the timing of harvest in any of the cultivars. Fruit collected before dawn exhibited reduced levels of CO2 and ethylene emissions and had less external and internal damage as compared to fruit gathered in the morning. Nevertheless, the response was influenced by environmental conditions during development, as the occurrence, size, and extent of bruising, total internal damage, and tissue ruptures were highest during the year with the hottest summer. The distinctions between harvest treatments were less apparent in comparison. Implementing mechanical harvesting techniques at dawn effectively minimizes the harm inflicted on olive fruit.

MacEachern et al., (2023)[21] analyzed that wild blueberries, scientifically known as Vaccinium angustifolium Ait., have significant economic importance in eastern Canada. However, the sector is confronted with substantial manpower shortages necessary to gather the more than 69,000 hectares of wild blueberry acreage annually. Wild blueberry automation is a prominent focus of wild blueberry research. Currently, the need to automate several components of the harvester necessitates the presence of an operator in the tractor. Throughout the whole duration of the trial, the proficient operator saw a 13.83% reduction in average heart rate while using the completely automated condition compared to the fully manual condition. In the identical circumstance, the new operator saw a reduction of 19.03% in average heart rate. The respiration rate data did not show a definitive pattern, while the greatest respiration rates were seen during entirely manual harvesting, except for the 2022 new operator data. Overall, this research establishes a solid foundation for the use of automation to tackle the scarcity of competent personnel and to eventually achieve complete automation of the wild blueberry harvester.

Panduangnate et al., (2023)[22] The objective of this study was to provide a novel method for determining the proportion of waste in mechanically collected sugarcane samples by using multispectral photography and machine learning. The study determined that the Random Forest model, with a Classification Tree of 150, had the highest level of effectiveness among the classification models. It achieved a Quality Percentage of 96.05%. Furthermore, the most accurate prediction models for determining the weight of sugarcane billet using Multiple Linear Regression exhibited an R2 value of 0.77 and a Root Mean Square Error of calibration (RMSEC) value of 21.03 g. The study findings also shown that the novel technology has the ability to precisely estimate the proportion of waste in sugarcane samples, exhibiting a Root Mean Square Error of prediction (RMSEP) of 2.09% in comparison to conventional techniques. This implies that the novel technology has the potential to be an effective and efficient approach for evaluating the proportion of sugarcane billet and garbage in manufacturing procedures.

Khatri et al., (2022)[23] Due to a growing desire to complete the mechanical harvesting process in citrus farming, the use of harvesting instruments has become a dependable choice for citrus harvesting. However, there is a lack of documented research on the performance and post-harvest storability of manual harvesting instruments for mandarin picking in Nepal. This research evaluated the effectiveness of several manual fruit harvesters by analyzing their harvesting yield, operational characteristics, post-harvest physio-chemical properties, and the shelf life of mandarin fruits held at room temperature for 26 days. The study examined six different harvesting methods: a) Farmer practice-hand picking (FPground), b) Ladder climbing (FPladder), c) Secateur + ladder climb (SEladder), d) Cut and hold type picking shears (CH), e) Long reach finger type fruit picker (LRF), f) Fruit picker with basket and cushion (PHB). The harvesting capacity of the FPground, FPladder, SEladder, LRF, CH, and PHB treatments were 60.6±2.26, 33.43±3.13, 24.25±2.25, 43.85±6.34, 61.30±9.28, and 49.13±2.61 kg/hr, respectively. The CH, LRF, and PHB type harvesters had harvesting outputs that were 39.15% (779 nos/hr), 15.78% (648 nos/hr), and 30.21% (729 nos/hr) greater than the FPladder practice (560 nos/hr), respectively. On the other hand, the SEladder technique had a harvesting output that was 15.62% (442 nos/hr) lower than the FPladder. SE and CH were shown to be beneficial in enhancing the storability of mandarins, resulting in a longer shelf life and better quality compared to FP and PHB. The reduced pedicle length in the fruit treated with SE, CH, and LRF helps to manage and slow down the leakage of sap, decrease weight loss, prevent lateral infection, maintain fruit firmness, and limit damage and decay.

Bont et al., (2022)[24] Efficient forest operations are necessary to ensure the supply of biodiversity and a wide range of ecosystem services, including wood production, carbon sequestration, protection against natural disasters, and recreation. Forest management and harvesting expenses are not offset by wood income in many nations, particularly in challenging terrain conditions. An efficient strategy to improve the cost-effectiveness of the forestry industry is to use cutting-edge harvesting and extraction techniques, sometimes referred to as the most appropriate ways for harvesting. In this study, we focus on the forestry sector in Switzerland, specifically examining the issue of low competitiveness. Our objective is to measure the potential efficiency improvements that could be achieved by implementing the most suitable harvesting methods, as opposed to the methods currently in use. To achieve this goal, we created a spatial decision support system that assigns the most appropriate harvesting techniques to plots based on anticipated suitability. This system also takes into account constraints in hauling routes, attributes of extraction routes, and characteristics of the stands. Our investigation yields three significant conclusions: Our modeling methodology is a very successful strategy for assigning the most appropriate harvesting methods to NFI plots based on assessed suitability. Furthermore, using the most accurate and appropriate harvesting techniques would result in decreased costs, especially in areas with steep topography where harvesting mostly depends on cable and air extraction methods. Enhancing the cost-effectiveness of the forestry industry is globally significant, since using domestic wood resources more extensively is a financially viable method to decrease atmospheric carbon emissions. The methodological framework outlined in this document was specifically designed for implementation in Switzerland. However, it has the potential to be adapted and used in other regions of Europe, particularly in Central Europe and areas with extensive mountain forests.

Du et al., (2021) [25] The oil-tea camellia tree, a significant oil crop in China, is characterized by its long and pliable branches. The main difficulty in robotic harvesting of oil-tea fruits is in the synchronized growth of its flowers and fruits. A handheld fruit harvesting machine equipped with a comb brush that can be adjusted for different spacing was suggested as a means to enhance harvesting efficiency and prevent harm to the flower bud. The harvesting machine is capable of producing three types of actuation in order to separate fruit during operation. The primary actuation is achieved by the contact of numerous comb fingers. Two other forms of actuation occur when the comb fingers strike the fruits and branches. The spacing between the teeth of the comb brush may be altered by sliding the spacing adjustment crossbar. Therefore, if the distance between the fingers is less than the diameter of the oil-tea fruit, the fruit is removed by brushing, but the flower bud and leaf may pass through the space between the fingers. When the distance between the fingers is greater than the diameter of the fruit, the fruit that gets trapped between the fingers is released to guarantee the uninterrupted functioning of the machine. The brush finger was constructed using nylon material to prevent any potential harm and also to minimize the overall weight. The harvesting machine was dynamically simulated using ADAMS to examine the acceleration of the front end of the comb finger and the modification of the finger spacing. The first version of the harvesting equipment was constructed and evaluated in the field. The field trial findings showed that at a speed of 480 revolutions per minute (r/min), the average oil-tea fruit harvesting percentage reached 80%, with little detachment of flower buds. This speed level successfully fulfilled the operational criteria for oil-tea fruit harvesting.

Zhang et al., (2020) [26] examined the overview of the advancements in mechanical harvest technology for fresh market apples in recent decades, specifically focusing on the shake-and-catch, robots, and harvest-assist platform approaches. Furthermore, the assessment highlights the limitations and upcoming developments of these three technological groups. Significant advancements in the shake-and-catch technique are attributed to theoretical research on optimizing apple removal and implementing capturing devices to reduce bruising. The unfavorable bruise circumstances impede the commercial use of the shake-and-catch approach. Two firms specializing in the development of apple harvesting robots are now in the process of bringing their goods to the market. One company is focusing on a vacuum-based system, while the other is using a three-finger end-effector. The economic advantages, as well as the technological dependability and resilience of both robots, are awaiting certification prior to their release on the market. Furthermore, a significant challenge encountered by both robots prior to being used commercially is to discover a resolution for harvesting apples that are cultivated in clusters. Apple producers are slowly embracing the use of harvest-assist systems, while their adoption rate remains low owing to skepticism about the economic advantages. Enhancing the adoption of harvest-assist platforms might be achieved by the validation of their economic advantages and the integration of other functions, such as sorting. Due to the fast advancement of sensing and automation technologies, including innovative sensors, embedded systems, and machine learning algorithms, as well as the improvement in new tree canopy structures that make it easier to see and reach fruit, it is expected that robots for harvesting fresh market apples will be developed and made available for commercial use soon. Presently, it is essential to allocate further resources towards the analysis and verification of the economic advantages offered by harvest-assist platforms. Additionally, enhancing the functionality of these platforms should be prioritized to augment their use within the apple business.

Panfilova et al., (2020) [27] studied that the physical and mechanical characteristics of berries, as well as the morphometric properties of the bush's growth habit, are crucial factors in determining the suitability of berry harvesting equipment. This study focused on examining six different red currant cultivars. The berry separation force, crushing force, and strength of attachment of the berries to the stem were quantified using the "PLODTEST-1" and "Dina-2" machines from Russia to assess their physical and mechanical properties. To optimize the performance of the berry harvester, it is essential for the crushing force exerted on the berries to be more than 2 N, while the force required to separate the berries should be between the range of 0.5-1.5 N. A robust positive connection was observed between the separation and crushing forces, with a correlation value (R) of 0.71. During the technical maturity period, the adhesion strength of the berries on the raceme surpassed 0.5 N. However, when maturation neared its completion, this metric decreased. Most of the cultivars that were studied have a compact and optimal bush size. The red currant cultivars Niva, Asya, and Vika have significant promise for mechanized harvesting.

Zhang et al., (2020) [28] discussed the diminishing availability of competent harvest labor poses a significant challenge to the sustainability of fresh market apple production in the USA. Mass mechanized apple harvesting is a viable and encouraging alternative. It is important to have a thorough understanding of the fundamental canopy elements of apple trees, since they are closely linked and have an impact on the design of harvesters throughout the harvesting process. This study investigated the impact of eleven canopy attributes on the mechanical harvesting of "Scifresh" trees trained in a vertical manner and "Envy" trees grown using a V-trellis system. The research was carried out during the harvesting experiments. We used a supervised machine learning methodology that incorporated weighted k-nearest neighbors (kNN) to examine our canopy datasets. A total of 2678 ground-truth data points (apples) were divided into two binary classes depending on the condition of fruit removal: "mechanically harvested" and "mechanically unharvested" apples. The selected methodology achieved prediction accuracies of 76-92% and 62-74% for the "Scifresh" and "Envy" cultivars, respectively, in the training dataset, which accounted for 85% of the data. The test accuracies for "Scifresh" using the remaining 15% of the sample varied between 81% and 91%, whereas for "Envy" they varied between 36% and 79%. Principal components analysis (PCA) was used to determine the fundamental canopy attributes by calculating the coefficients of principal components (PCs). PC1–PC5 explained at least 80% of the variability in the data. The most significant parameters observed were fruit load per branch, branch basal diameter, and shoot length, with a coefficient greater than 0.5 suggesting a high level of importance. These findings provide valuable advice for farmers on the management of the canopy, which has the potential to enhance the effectiveness of a mechanical harvesting system.

Maponya et al., (2020) [29] Timely crop categorization data, preferably obtained before to harvest, is crucial for predicting food availability or shortage. This study assesses the effectiveness of several machine learning classifiers, such as SVM (support vector machine), DT (decision tree), k-NN (k-nearest neighbor), RF (random forest), and ML (maximum likelihood), in successfully identifying different kinds of crops by analyzing a series of Sentinel-2 satellite images. Four experiments were undertaken, each using unique combinations of photo sets. The first three experiments included the use of 1) singular pictures taken at a certain moment; 2) combinations of five images selected from the most efficient individual images; and 3) five images manually selected based on the development stages of the crops. In the fourth trial, images were added one by one in sequence to assess the performance of the classifiers using just pre-harvest shots. The goal was to identify the earliest moment in the season when acceptable levels of accuracy might be achieved. The research was carried out in two separate sites in the Western Cape Province of South Africa, with the goal of perfectly replicating the grain-producing districts in the area, which are known for their Mediterranean climate. A study was done to evaluate the influence of image selection on classification accuracies and the performance of machine learning classifiers, particularly when only pre-harvest pictures are used. The analysis of the classification results included the assessment of both the overall accuracies and kappa coefficients. McNemar's test and ANOVA (analysis of variance) were used to assess the statistical significance of the differences in accuracies observed in various studies. The results suggest that picking photos based on individual performance is a viable option instead of choosing images based on crop developing phases. Moreover, the accuracy in classifying crops using the whole time series is similar to that achieved when utilizing a selection of manually chosen photos. Our research suggests that Support Vector Machines (SVM) and Random Forest (RF) models may attain a high level of accuracy (77.2%) in classifying data as early as eight weeks before the harvest. This result indicates that pre-harvest photographs have the capacity to accurately identify crops, thereby providing substantial potential for mapping crop types across the whole growing season.

Williams et al., (2019) [30] With the increasing difficulty of meeting labor demands in horticulture, automated solutions are proving to be a viable method for maintaining production and quality. This study introduces a new kiwifruit harvesting robot with many arms, which is specifically built to work independently in orchards with pergola-style structures. The paper also includes an assessment of the robot's performance. The harvester is equipped with four specialized robotic arms, each with a unique end-effector intended to safely pick kiwifruit. The vision system utilizes state-of-the-art deep neural networks and stereo matching techniques to accurately recognize and precisely locate kiwifruit in various lighting situations seen in real-world environments. Additionally, a new and innovative fruit scheduling system has been created to efficiently coordinate the four arms throughout the harvesting operation. The harvester's performance has been assessed via an extensive and authentic field testing conducted in a commercial orchard setting. The findings indicate that the harvester being discussed can effectively harvest 51.0% of the overall quantity of kiwifruit in the orchard, with an average duration of 5.5 seconds per fruit.

3. Expenditures involved in manual and mechanical harvesting

The details of manual and mechanical harvesting charges incurred by the respondents are given in Table 1 [31].

Table 1. Expenditure involved in manual and mechanical harvesting

Parameter	Manual Harvesting	Mechanical Harvesting

Total area harvested in acres	163.35	99.3
Total cane produced (tonnes)	5151	3775
Total charge paid (Rs.)	29,99,415582/ton	16,98,750450/ton
Other related expenses (Rs.)	1,96,02038 38per ton	97,39026 Rs.26/ton
Total charges for harvesting in Rs.	31,95,435	17,96,140
Harvesting charge per ton in Rs.	620.35	476
% in cane price	28.5	21.1

- **Expenditure involved in Manual harvesting**

The respondents physically harvest a total area of 163.35 acres of sugarcane, resulting in a yield of 5151 tons. The mean production in this area is 31.53 tons per acre. The mean fee for harvesting is Rs 582 per metric ton of cane. It should be emphasized that an amount of Rs. 38 per tonne of cane is allocated for various associated expenses, such as transportation costs for workers from the villages or neighboring areas to the field, as well as providing 'karikkasu'. The tradition of providing 'karikkasu' or 'kallakkasu' or 'quarterkasu' as a kind of payment to workers on the last day of the harvest is a recent practice that has imposed an extra financial strain on the sugarcane planter. The laborers are demanding that this practice be implemented, since it ensures their continued employment with the same farmer in the next season. Another issue to consider is the gradual increase in the harvesting charge over time. Typically, this charge is lower during the early season and rises throughout the latter stages of the crushing season. During manual harvesting, cane farmers allocate 29% of the cane price on hiring laborers. An increase in the harvesting fee will lead to a decrease in the cane grower's net profit. The expensive fee for harvesting and the failure of sugar mills to pay have deeply irritated several cane producers, and this issue is progressively escalating in severity each year.

- **Expenditure involved in Mechanical harvesting**

The mechanical harvesters were used to harvest a total area of 99.30 acres, resulting in a cane yield of 3775 tons. The mean productivity in this location is 33.98 tons per acre. Typically, farmers incur a cost of Rs 450 per tonne for mechanical harvesting, which is much lower than the cost of Rs 582 for hand harvesting. The respondents bear a cost of Rs.26 per tonne for providing meal allowance to the operators of harvesters and salaries to the scrap/cut cane collectors in the field. One important factor to consider when paying for mechanical cane harvester's harvesting charge is that the cost remains constant throughout the crushing season, unlike manual harvesting where the cost starts at a reasonable level in the beginning of the season and becomes excessively high in the later months. The cane farmers allocate 21% of the cane proceeds towards the cost of cane harvesting when using mechanical cane harvesters, which is 7% lower compared to hand harvesting.

4. Challenges between Manual and Mechanical harvesting in Agriculture

The transition from manual to mechanical harvesting in agriculture presents several challenges, each with distinct implications for efficiency, cost, and labor dynamics are described given below [32].

1. Labor Intensity and Availability

Manual Harvesting:

Labor Intensive: Manual harvesting requires a large workforce to perform tasks by hand, which can be physically demanding and time-consuming.

Labor Shortages: In many regions, there is a growing scarcity of agricultural laborers due to urban migration and an aging rural population, leading to difficulties in finding sufficient workers during peak harvest seasons.

Mechanical Harvesting:

Reduced Labor Need: Mechanical harvesting significantly reduces the need for manual labor, potentially mitigating issues related to labor shortages.

Skilled Operators: However, it requires skilled operators to manage and maintain the machinery, which can be a challenge if such expertise is not readily available.

2. Efficiency and Speed

Manual Harvesting:

Slower Process: Manual harvesting is generally slower compared to mechanical methods, which can affect the timely harvesting of crops, especially in large-scale farming operations.

Precision: Despite being slower, manual harvesting allows for more precise selection and handling of crops, reducing damage and waste.

Mechanical Harvesting:

High Efficiency: Mechanical harvesters can cover large areas quickly, significantly increasing the speed of harvesting operations.

Potential Crop Damage: The machinery may cause more damage to crops, particularly if the crops are delicate or the machinery is not properly adjusted for specific conditions.

3. Cost Considerations

Manual Harvesting:

High Labor Costs: The cost of employing a large workforce can be substantial, especially in regions with higher labor wages.

Variable Costs: Labor costs can fluctuate based on availability, seasonal demand, and local economic conditions.

Mechanical Harvesting:

High Initial Investment: The initial cost of purchasing, maintaining, and operating harvesting machinery is significant.

Long-Term Savings: Over time, the investment in machinery can lead to cost savings by reducing the dependency on manual labor and increasing operational efficiency.

4. Crop Suitability and Adaptation

Manual Harvesting:

Versatility: Manual methods can be adapted to a wide variety of crops, including those that are delicate or irregular in shape and size.

Selective Harvesting: Workers can selectively harvest ripe crops, which is particularly important for certain types of fruits and vegetables that do not ripen uniformly.

Mechanical Harvesting:

Limited Adaptability: Some machines are designed for specific crops and may not be suitable for others, limiting their versatility.

Uniform Ripeness Required: Mechanical harvesters are generally more effective with crops that ripen uniformly, which can be a limitation for certain agricultural practices.

5. Environmental Impact

Manual Harvesting:

Lower Environmental Footprint: Manual harvesting typically has a lower environmental impact in terms of energy consumption and greenhouse gas emissions.

Sustainable Practices: It can be more easily integrated with sustainable farming practices, such as organic farming, which rely less on heavy machinery.

Mechanical Harvesting:

Higher Energy Consumption: The use of machinery increases energy consumption and can contribute to higher greenhouse gas emissions.

Soil Compaction: Heavy machinery can cause soil compaction, affecting soil health and crop yields in the long term.

6. Quality Control

Manual Harvesting:

Higher Quality Control: Workers can inspect and handle each crop individually, ensuring higher quality and reducing the incidence of damaged or spoiled produce.

Labor Fatigue: However, the quality of manual harvesting can be affected by worker fatigue and varying skill levels.

Mechanical Harvesting:

Consistent Performance: Machines can provide consistent performance without the variability associated with human labor.

Quality Issues: Despite the consistency, mechanical harvesting may still result in higher levels of crop damage, particularly if the machinery is not properly maintained or calibrated.

The choice between manual and mechanical harvesting in agriculture involves a complex balance of labor availability, cost, efficiency, crop suitability, environmental impact, and quality control. Each method has its own set of challenges and benefits, and the optimal approach may vary depending on the specific context and needs of the farming operation.

5. Mechanisation 2.0: The Future of Agriculture

Furthermore, emphasizing the integration of technology in agricultural mechanization will enhance the development prospects of the industry, in addition to the national driving factors described earlier. In the Indian context, these technical improvements are often known as Mechanization 2.0, and the following information provides coverage on this topic [33]. The agricultural industry is on the verge of undergoing the same technological advancements that are already flourishing in India's major economic sectors. The agricultural business would greatly benefit from advancements in technology, such as the acquisition of technical farming knowledge, the evaluation of soil conditions, weather forecasting, yield forecasting, and any other activities that lead to increased crop production. The term 'AgriTech start-ups' is often used to describe enterprises that provide technical interventions or technological solutions to benefit agriculture and associated sectors. India is among the top six countries globally in terms of the magnitude of agricultural technology transactions. India hosts around 11% of all AgriTech start-ups globally, as reported by prominent industry study. India now accommodates over 450 agritech start-ups, seeing an annual growth rate of 25%. Due to the increasing focus and range of technology integrations in the farm mechanisation sector, four distinct areas of AgriTech themes that are relevant to this industry have been identified. The future progression of farm mechanisation and the overall agricultural sector of the country will be propelled by the development of technology in these specific areas. Bulk density of rice husk and rice straw was 331.59 kg/m^3 and 380.54 kg/m^3 respectively [36]. The percentage of blown pods, un threshed pods, broken pods and spilled pods were observed as 14.51, 18.92, 0.126, 1.04% and 6.07, 14.59, 0.361, 0.99% for GG-22 and GG-20 varieties, respectively [40}.

The four identified categories are

1. Farming as a Service (FAAS)

2. Big data-based mechanisation technologies

3. Internet of Things (IoT) mechanisation technologies

4. Artificial intelligence (AI) mechanisation technologies

Collectively, these future technology solutions have been named as ‘Mechanisation 2.0’.

5.1 Role of Mechanisation 2.0 in developing Farming as a Service (FAAS)

An essential category of agricultural start-ups in India is Farming as a Service (FAAS). FAAS start-ups specialize on implementing specific agricultural methods that provide technologically advanced services, such as the rental of farming equipment. FAAS aims to provide cutting-edge and cost-effective agricultural equipment for optimal and productive farming. Start-ups in the FAAS category aspire to provide small and marginal farmers more cost-effective agricultural practices by converting fixed expenses into variable costs. FAAS often operates by creating a mobile application that connects farmers and allows them to share and trade machinery and equipment, therefore addressing the imbalance between supply and demand. This platform enables tractor and agricultural equipment owners to establish connections with clients. This unique technique enhances farmers' earnings by effectively resolving the demand and supply challenges faced by tractor owners and those seeking their services. An ideal win-win scenario occurs when both parties can avoid the need to purchase new equipment, resulting in cost savings. Meanwhile, the owner of the existing tractor or machine may enhance the equipment's economic performance, leading to an increase in revenue. Figure 3 depict the role of technology in FaaS as shown below.

Figure 3. Role of Technology in FaaS [34]

These technologies not only assist in the daily activities of farming but also play a role in ensuring long-term sustainability and making data-based decisions in agriculture.

Precision Farming Technologies: Precision agriculture, an integral part of Farming as a Service (FaaS), employs GPS technology, sensors, and imagery to improve field-level management. GPS technology enables precise mapping of agricultural areas, allowing for efficient execution of planting, fertilizing, and harvesting procedures. Field sensors provide crucial information on soil quality and climatic conditions, enabling farmers to make informed decisions.

Internet of Things (IoT) and Big Data: Agricultural IoT devices collect vast amounts of data from many sources, including soil sensors, weather stations, and drones. Examining this data may uncover patterns and understandings that lead to improved use of resources, heightened agricultural efficiency, and reduced environmental impact.

Artificial Intelligence (AI) and Machine Learning (ML): AI and ML algorithms use data collected by IoT devices to provide farmers predictive insights. These technologies has the capability to predict weather patterns, forecast insect infestations, and suggest optimal dates for harvesting, therefore improving farm management via the adoption of a proactive rather than reactive strategy.

Drones and Robotics: Drones are used for conducting airborne assessments of fields, offering detailed observations on crop vitality, soil conditions, and other relevant factors. Robotics, however, are becoming more and more used for activities like as planting, weeding, and harvesting, which decreases the need for human labor and enhances accuracy in agricultural operations.

Automated Irrigation Systems: These systems use data gathered from sensors to produce precise irrigation schedules, ensuring that crops get the correct amount of water at the most favorable moment. Consequently, the conservation of water leads to an improvement in agricultural productivity.

The incorporation of these technology into farming techniques signifies a substantial advancement in agricultural productivity. Farming as a Service (FaaS) enhances the sustainability and productivity of farming by offering farmers in-depth information and automating labor-intensive tasks.

5.2 Mechanisation 2.0 around big data

Big data collection in the agricultural industry involves acquiring precise data from diverse sources, including rainfall, fertilizer needs, soil moisture, market prices, and selling locations. This data is then utilized to assist farmers in making well-informed decisions that can result in effective problem-solving and profitable outcomes. A farmer can utilize historical data on crop yields, input requirements, soil nutrient levels, current weather patterns, available farm equipment, market connections, and current and projected prices to make well-informed decisions regarding which crop to cultivate, the appropriate planting time, the optimal land area for cultivation, the ideal harvest time, and the most suitable market for selling the produce.

5.3 Mechanisation 2.0 around Internet of Things (IoT)

The Internet of Things (IoT) refers to a network of linked IT technologies, such as remote sensing, drones, GPS, sensors, automated hardware, and robots. Utilizing IoT-based smart agriculture in agricultural activities enhances the yield. India prioritizes precision agriculture. Therefore, most equipment manufacturers are ensuring the integration of the aforementioned technologies to enhance the effectiveness of their goods and get a competitive advantage in the market.

5.4 Mechanisation 2.0 around Artificial Intelligenc

The objective of Artificial Intelligence (AI) is to develop robots and computers capable of exhibiting intelligent behavior or responses similar to those of humans. Algorithms developed with comprehensive information, historical data, and current data may assist in implementing precise and intelligent agricultural procedures on the farm. Artificial intelligence (AI) may be used to automate several agricultural activities, including weed removal, spraying, and crop harvesting, therefore enhancing production and precision. The use of artificial intelligence in the field of agriculture is still in its nascent phase, although it is rapidly progressing in response to the need for enhanced productivity at reduced expenses.

6. Conclusion

To summarize, the analysis of human and automated harvesting demonstrates an intricate interaction of variables that impact agricultural methods. Manual harvesting, known for its labor-intensive nature, provides meticulousness and attentiveness, which are crucial for fragile crops, but is impeded by exorbitant labor expenses and the possibility of labor scarcities. On the other hand, mechanized harvesting improves productivity and velocity, allowing for the quick gathering of substantial amounts of crops and decreasing reliance on seasonal workforce. Nevertheless, this approach requires substantial upfront investment in equipment and continuous upkeep, which may not be viable for smaller agricultural operations. In addition, mechanical harvesting may result in crop and soil damage and lacks the flexibility to handle various crop kinds and terrains, which is a characteristic of manual approaches. Notwithstanding these obstacles, the future of agriculture is expected to see a growing incorporation of automation, propelled by technological breakthroughs and the need for environmentally-friendly and expandable agricultural methods.

With the evolution of the agricultural industry, there is potential for a hybrid strategy that combines the advantages of human and mechanical techniques. This approach aims to maximize output while ensuring crop quality and environmental sustainability.

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